Efficient Design of Multiple-fed Leaky Wave/Fabry-Perot Antennas

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***Abstract*——A simple transmission line approach for the rapid analysis of multiple fed Leaky Wave antennas based on Fabry-Perot cavities is presented. The method is based on the superposition of the travelling leaky waves excited by each of the applied source. The propagation constant of the leaky waves inside the Fabry-Perot cavity is computed the Transverse Resonance Technique (TRM). The procedure is completely analytic since the antenna does not require a superstrate composed by unconventional FSS elements. This antenna configuration allows the synthesis of very high gain antennas while preserving reasonable bandwidth.**

Keywords— Antenna arrays, Fabry Perot antennas, Leaky Wave Antennas, Metamaterials.

I. INTRODUCTION

Leaky antennas based on Fabry-Perot (FP) cavities have received a considerable attention in the last few years. In its simplest version, the antenna comprises a partially reflecting surface (PRS) at a half-wavelength distance from a metallic ground. The antenna can be fed in the center to obtain a broadside radiation pattern [1]. These antennas have the advantage, with respect to linear or planar arrays, of providing high directivity without a feeding network. However, when the required antenna gain is too large, the illumination of the entire aperture with a single feed becomes challenging. In order to do that, a partially reflective surface with a amplitude reflection coefficient very close to the unity has to be employed. This allows to reduce the leakage rate of the leaky wave propagating inside the cavity and thus improve the illumination efficiency [2]. However, higher gain is paid in terms of operating bandwidth: the quality factor of the FP cavity increases and the antenna becomes extremely narrowband both in terms of gain and in terms of matching [3]. An additional and not negligible disadvantage of very high-quality factor cavities is that the simulation of the structure becomes critical. A technique to improve the aperture illumination and thus allowing the synthesis of very high gain radiators with a reasonable bandwidth is the use of multiple sources to excite the FP cavity [4], [5]. The feeders are spaced much more than one wavelength and, for this reason, the antenna can be seen as array thinning technique [4]. When more than one source is employed, the electric field distribution inside the cavity is due to the composition of the leaky waves excited by each feeder. Multi-fed FP antennas have been also proposed to reduce sidelobe level with respect to arrays [6] or to perform a limited scan of the beam by opportunely choosing the element phases [7]. In the case of multi-feed, the superstrate can be a standard inductive or capacitive FSS [8], [9] and it geometry can be modified to select the appropriate leakage rate. The design is usually performed by using full-wave approach but this can be very expensive from a computational point of view and time. Here a simple transmission line approach to analyze the multi-feed leaky antennas is proposed. The method allows to easily control the high number of degrees of freedom involved in the design.

II. ANALYZED STRUTURE

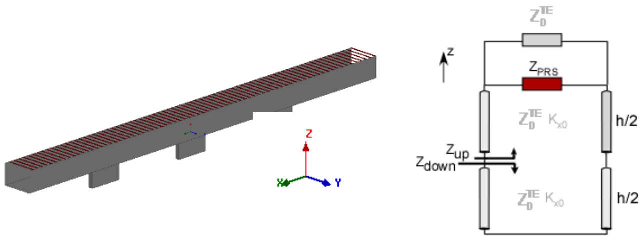
The leaky antenna under analysis, reported in Fig. 1a, is composed by a Fabry-Perot cavity excited by multiple waveguides. The feeding elements can be also patch antennas or other non-directive radiators [10]. The Fabry-Perot cavity consists of a waveguide closed on top with a partially reflecting surface. In this case the PRS is formed by a strip grating. The geometrical properties of the strip array determines the reflectivity level of the PRS and this allows to choose the leakage rate of the travelling leaky wave. The designed structure can be also seen an overlapped array of leaky wave antennas. Choosing high leakage rate guarantees (low FSS reflectivity) a large operating bandwidth and a limited overlap is obtained while low leakage rate determines highly directive element pattern and remarkable overlapping. The number of feeds has to be chosen for guaranteeing an efficient illumination of the aperture once that the PRS geometry and thus the leakage rate is chosen. By exciting the feeding elements with a proper phase, it is also possible to perform a moderate bean scanning. In this case, the limitation is given by the element spacing and single element pattern shape. The larger is the distance among the feeders, the more directive is the element pattern and thus the scan range diminishes.

III. RADIATION PATTERN COMPUTATION WITH THE TRANSMISSION LINE APPROACH

The method here proposed for the analysis of array feed Fabry-Perot antennas is based on a Transmission Line Equivalent of the FP cavity. The first step of the procedure is the calculation of the complex propagation constant inside the cavity. This is done through the Transverse Resonance Method (TRM) [1]. To this aim, the transverse transmission line model of the Fabry-Perot cavity reported in Fig. 1b is employed. The propagation constant k_x=β-jα is obtained by solving the following dispersion equation with a numerical approach:

$$Z_{down} + Z_{up} = 0 \tag{1}$$

The impedances Z_{up} and Z_{down} are defined as in Fig. 1b and represent the impedance seen looking towards up and down at a generic section of the transmission line. The impedance of the strip PRS is purely inductive its expression is analytically known [11].



(a) (b)

Fig. 1 – (a) Analysed leaky antenna configuration. (b) Transverse Equivalent Network of the FP cavity.

Once that the complex propagation constant is computed, the filed inside the cavity is derived by the superposition of the electric fields (voltage in the equivalent transmission line) radiated by each source. Indeed, each source excites two leaky waves towards opposite directions.

As an example, we consider a FP cavity excited by three slots. The spacing among exciting slots is 75 mm. The total length of the antenna is 300 mm and its height is equal to 14.5 mm. The PRS layer is formed by a strip grating characterized by a periodicity of 4 mm and a strip width of 1 mm. The electric field distribution inside the cavity, obtained by the superposition of the leaky waves, is reported in Fig. 2. The pattern of the antenna on φ=0° have been computed both with the transmission line model and by using Ansys HFSS. The result of Fig. 3 shows good agreement between the proposed simplified approach and the FEM full-wave simulation which lasted several hours.

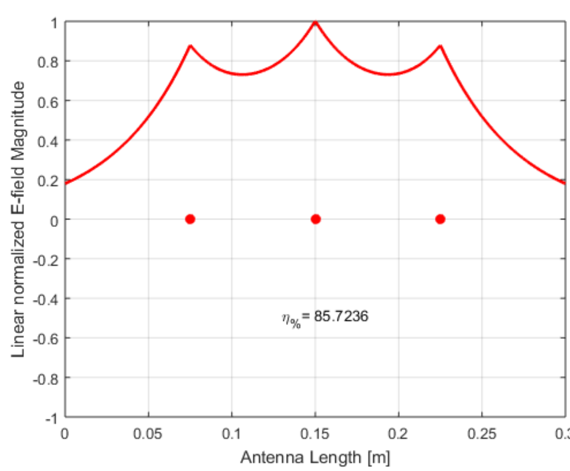


Fig. 2 – Electric field distribution inside the FP cavity computed by the TL approach.

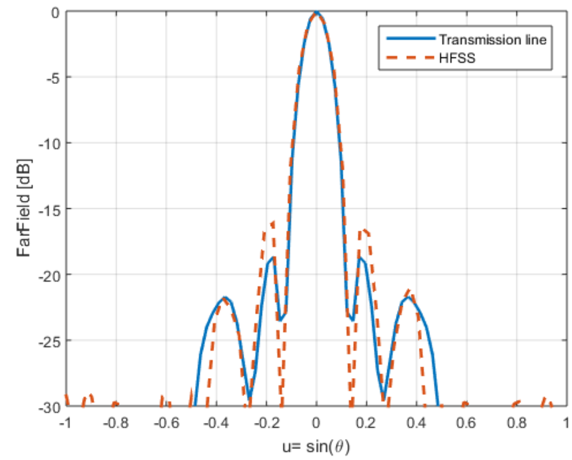


Fig. 3 – Radiation pattern on φ=0° computed with HFSS and with the proposed TL approach.

Conclusions

Multiple fed leaky wave antennas based on Fabry-Perot cavities are analyzed by a simple transmission line model. This approach an efficient design and analysis of the antenna without recurring to time consuming full-wave simulations.

References

[1] G. Lovat, P. Burghignoli, and D. R. Jackson, “Fundamental properties and optimization of broadside radiation from uniform leaky-wave antennas,” *IEEE Trans. Antennas Propag.*, vol. 54, no. 5, pp. 1442–1452, May 2006.

[2] M. Garcia-Vigueras, J. L. Gomez-Tornero, G. Goussetis, A. R. Weily, and Y. J. Guo, “1D-Leaky Wave Antenna Employing Parallel-Plate Waveguide Loaded With PRS and HIS,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 10, pp. 3687–3694, Oct. 2011.

[3] R. Sauleau, “Fabry–Perot Resonators,” in *Encyclopedia of RF and Microwave Engineering*, John Wiley & Sons, Inc., 2005.

[4] R. Gardelli, M. Albani, and F. Capolino, “Array thinning by using antennas in a Fabry-Perot cavity for gain enhancement,” *IEEE Trans. Antennas Propag.*, vol. 54, no. 7, pp. 1979–1990, Jul. 2006.

[5] M. Hajj, E. Rodes, D. Serhal, Mon&#233, di&#232, T. Re, and B. Jecko, “Design of Sectoral Antennas Using a Metallic EBG Structure and Multiple Sources Feeding for Base Station Applications,” *Int. J. Antennas Propag.*, vol. 2008, p. e359053, Feb. 2009.

[6] N. Llombart, D. Blanco, E. Rajo-Iglesias, J. Campuzano, and A. Montesano-Benito, “Leaky wave enhanced phased array for the reduction of the grating lobe level,” in *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, 2012, pp. 1–2.

[7] J. Kim, M.-G. Kim, and R. Mittra, “Scan capability of fabry perot cavity (FPC) antennas with array feeds,” in *IEEE Antennas and Propagation Society International Symposium (APSURSI)*, 2012, pp. 1–2.

[8] B. A. Munk, *Frequency Selective Surfaces: Theory and Design*. John Wiley & Sons, 2005.

[9] F. Costa, A. Monorchio, and G. Manara, “An Overview of Equivalent Circuit Modeling Techniques of Frequency Selective Surfaces and Metasurfaces,” *Appl. Comput. Electromagn. Soc. J.*, vol. 29, no. 12, pp. 960–976, 2014.

[10] M. Degiorgi, F. Costa, S. Genovesi, and A. Monorchio, “A sectorial Fabry - Perot antenna for radar application,” in *2015 9th European Conference on Antennas and Propagation (EuCAP)*, 2015, pp. 1–5.

[11] O. Luukkonen, C. Simovski, G. Granet, G. Goussetis, D. Lioubtchenko, A. V. Raisanen, and S. A. Tretyakov, “Simple and Accurate Analytical Model of Planar Grids and High-Impedance Surfaces Comprising Metal Strips or Patches,” *IEEE Trans. Antennas Propag.*, vol. 56, no. 6, pp. 1624–1632, Jun. 2008.